
Raytheon

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Development and Integration
(ATMSDI)**

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Draft Guidelines
Subtask 1 – Distributed Decision-Making**

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NASA Ames Research Center
Richard Mogford, Ph.D.

Prepared by

Raytheon ATMSDI Team
Parimal Kopardekar, Ph.D. and Nicole Sacco (Titan Systems)

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FOREWORD

Distributed decision-making (DDM) is the backbone of Distributed Air-Ground Traffic Management (DAG-TM). The DAG-TM decision-making process is distributed among air traffic controllers, traffic managers, flight crews, and airline operations center dispatchers. DDM inherently involves newer procedures and supporting decision support tools (DSTs) to facilitate an exchange of information among these participants. Therefore, researchers, system designers, and sponsors should use these guidelines for the development of procedures and DSTs and in addressing DDM related issues. This document provides initial guidelines related to DDM. The guidelines are based on the literature review, discussions with subject matter experts and researchers, and author experience. These initial guidelines will be updated in upcoming years of the Air Traffic Management System Development and Integration program.

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1. BACKGROUND

Distributed Air-Ground Traffic Management (DAG-TM) represents a paradigm shift which will bring profound changes to the roles and responsibilities of air traffic control service providers (ATSP), traffic flow management specialists (TFMS), flight crews (FC), and airline operations center specialists (AOCS). These new roles and responsibilities will require different decision-making styles and additional decision support tools and procedures. Since these changes will alter the human tasks, the human-machine interface, and the allocation of functions between these agents, it is imperative that we examine the roles and responsibilities of air/ground traffic agents and assess the impact of these changes on system design.

This document presents initial guidelines in relation to distributed decision-making (DDM) with a particular focus on *Concept Element (CE) 5: Free Maneuvering* and *CE 11: Self-Spacing for Merging and In-Trail operations*.

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2. SCOPE

These initial guidelines were developed based on literature review, discussions with subject matter experts, and the author's experience and opinions. These initial guidelines will be updated annually. It is recognized that the guidelines may not be complete this early in the concept exploration and validation stage. Therefore, a number of issues that need further investigation are identified. In essence, the advantage of developing early guidelines is that it will also identify gaps in the research where additional guidelines and human factors research and consideration are needed.

These guidelines are not meant to be a theoretical discussion of DDM rather a very focused perspective of DDM as applied to CE 5 and CE 11. These initial guidelines will be useful for National Aeronautics and Space Administration's (NASA's) Advanced Air Transportation Technologies (AATT) Human Factors and Operations Office.

The detailed literature review that served as a basis for these guidelines is provided in the Appendix and a focused literature review is used in the body of this document.

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3. OBJECTIVE

The objective of this document is to describe the guidelines related to distributed decision-making within the air traffic management (ATM) domain based on prior literature, research discussions, and human factors expertise.

Sections 4 and 5 describe DAG-TM CE 5 (En Route Free Maneuvering) and CE 11 (Terminal Self-spacing). These descriptions are taken from the DAG-TM concept definition documents developed by NASA Ames Research Center (NASA AATT, 1999).

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4. DESCRIPTION OF CE 5: EN ROUTE: FREE MANEUVERING FOR USER-PREFERRED SEPARATION ASSURANCE AND LOCAL TFM CONFORMANCE

It is noted that this concept element applies to all flight phases (Departure, Cruise and Arrival) in the operational domain of en route airspace.

4.1 Current Problem

(a) ATSP often responds to potential traffic separation conflicts by issuing trajectory deviations that are excessive or not preferred by users.

In the current air traffic control (ATC) system, trajectory prediction uncertainty leads to excessive ATC deviations for separation assurance. Due to workload limitations, controllers often compensate for this uncertainty (which may be equivalent to or greater than the minimum separation standard) by adding large separation buffers for conflict detection and resolution (CD&R). Although these buffers reduce the rate of missed alerts, some aircraft experience unnecessary deviations from their preferred trajectories due to the unnecessary “resolution” of false alarms (i.e., predicted “conflicts” that would not have materialized had the aircraft continued along their original trajectories). In those cases where a potential conflict really does exist, the buffers lead to conservative resolution maneuvers that result in excessive deviations from the original trajectory. Moreover, the nature of the resolution (change in route, altitude, or speed) may not be user-preferred. Due to a lack of adequate traffic, weather, and airspace restriction information (and the means to present such information), and also a lack of conflict resolution tools on the flight deck, current procedures generally do not permit the user to effectively influence controller decisions on conflict resolution.

(b) ATSP often cannot accommodate the user’s trajectory preferences for conformance with local traffic flow management (TFM) constraints.

The dynamic nature of both aircraft operations and NAS operational constraints often result in a need to change a 4-D trajectory plan while the aircraft is en route. Currently, the user (FC or airline operation center [AOC]) is required to submit a request for a trajectory change to the ATSP for approval. During flow-rate constrained operations, the ATSP is rarely able to consider user preferences for conformance. Additionally, a lack of accurate information on local traffic and/or active local TFM constraints (bad weather, special use airspace (SUA), airspace congestion, arrival metering/spacing) can result in the FC or AOC requesting an unacceptable trajectory. The ATSP is forced to plan and implement clearances that meet separation and local TFM constraints, but may not meet user preferences. Further negotiation between the ATSP and FC can adversely impact voice-communication channels and increase ATSP and FC workload.

4.2 Solution (Flight Deck Focus)

(a, b) Appropriately equipped aircraft accept the responsibility to maintain separation from other aircraft, while exercising the authority to freely maneuver in en route airspace in order to establish a new user-preferred trajectory that conforms to any active local TFM constraints.

While in the en route operational domain, appropriately equipped aircraft are given the authority, capability, and procedures needed to execute user-preferred trajectory changes without requesting ATSP clearance to do so. Along with this authority, the flight crew takes on the responsibility to ensure that the trajectory change does not generate near-term conflicts with other aircraft in the vicinity. The trajectory change should also conform to any active local TFM constraints (bad weather, SUA, airspace congestion, arrival metering/spacing). User-preferred trajectory modification may be generated by the FC with AOC input if appropriate, or generated entirely by the AOC and transmitted to the FC via datalink. The FC broadcasts its modified flight plan via datalink (includes notification of ATSP) immediately after initiation of trajectory modification; in most situations, this task is handled by on-board automation.

The ATSP monitors separation conformance for free maneuvering aircraft, and provides separation assurance for lesser-equipped aircraft using CD&R DSTs. The ATSP may act on behalf of lesser-equipped aircraft when they are in potential conflict with free maneuvering aircraft. For cases where the flight crew attempts, and fails, to resolve a conflict, automated systems or the ATSP will provide a required resolution. Procedures and flight rules are established that provide incentive for aircraft to equip for self-separation, such as, perhaps, priority status in conflicts with lesser-equipped aircraft.

Potential Benefits of CE 5 operation:

- Reduction in excessive and non-preferred deviations for separation assurance and local TFM conformance, due to the ability of the flight crew (for equipped aircraft) to self-separate and maintain local TFM conformance according to their preferences.
- Increased safety in separation assurance for all aircraft, due to communications, navigation, and surveillance (CNS) redundancy (FC as primary and ATC as backup) and increased situational awareness on the FC of appropriately equipped aircraft.
- Reduced ATSP workload for separation assurance and local TFM conformance plus reduced flight crew workload for communications, due to the distribution of responsibility for separation assurance and local TFM conformance between the ATSP and appropriately equipped FCs.

5. DESCRIPTION OF CE 11: TERMINAL ARRIVAL: SELF-SPACING FOR MERGING AND IN-TRAIL SEPARATION

5.1 Current Problem

Excessive in trail spacing buffers in arrival streams reduce runway throughput and airport capacity, especially in conditions of poor visibility and /or low ceilings.

In terminal area environments for which arrival demand approaches or exceeds capacity, aircraft landing rates are significantly lower under instrument meteorological conditions (IMC) than under visual meteorological conditions (VMC). In order to compensate for uncertainties in aircraft performance and position, the ATSP applies in-trail spacing buffers to arrival streams under IMC in order to ensure that minimum separation requirements between successive aircraft are met. The resulting generous arrival spacing reduces runway throughput below its capacity to accept aircraft.

5.2 Solution (Flight Deck Focus)

Appropriately equipped aircraft are given clearance to merge with another arrival stream, and/or maintain in-trail separation relative to a leading aircraft.

In VMC, aircraft are often able to maintain closer spacing during the approach, thereby increasing the capacity of the terminal area and the runway acceptance rate. In the current system, the FC is often requested to accept responsibility for visual self-separation once they acknowledge they can see the leading aircraft. In this situation, the FC is responsible for determining and then maintaining a safe separation from other aircraft, and is therefore not subject to the ATSP minimum separation requirements.

Self-spacing operations will enable the FC to autonomously merge with another arrival stream and/or maintain in-trail separation with another aircraft under IMC as they would under VMC, thus significantly increasing arrival throughput. Self-spacing applies to aircraft that are subject to spacing requirements during arrival, from the feeder fix, up to the final approach fix.

Anticipated procedures for self-spacing involve the ATSP transferring responsibility for in-trail separation to properly equipped aircraft, while retaining responsibility for separating these aircraft from crossing traffic. Once the FC receives clearance to maintain spacing relative to a designated leading aircraft, the FC establishes and maintains a relative position with frequent monitoring and speed/course adjustments. Under some conditions, information such as required time of arrival (RTA) at the final approach fix may be provided by an appropriate ATSP-based DST, thereby enabling accurate inter-arrival spacing that accounts for differing final approach speeds or wake vortex avoidance. ATSP monitors all aircraft to ensure adequate separation. For cases where the flight crew fails to maintain adequate spacing, automated systems or the ATSP will provide a required correction.

The self-spacing concept is expected to make use of datalink capabilities to provide position information and a cockpit display of traffic information (CDTI) and/or advanced flight director/head-up guidance technology to provide spatial and temporal situation awareness to the flight crew. FC-based DSTs will provide information to enable station-keeping and/or monitoring of automatic 4D trajectory management.

5.3 Potential Benefits

- Increased arrival capacity/throughput in IMC, due to a reduction in excessive spacing buffers resulting from the ability of appropriately equipped aircraft to operate as if they were in VMC.
- Reduced ATSP workload, due to transfer of separation responsibility to the flight crew of appropriately equipped aircraft.

6. IMPLICATIONS ON DECISION-MAKING FOR CE 5 AND CE 11

The efficiency and effectiveness of decisions under any style of decision-making depends largely on operator knowledge, situational awareness, quality and availability of information, and decision aids (Klein & Calderwood, 1991). Complex decisions, often made under uncertain situations (or based on forecast rather than actual information), lend themselves to suboptimal decision-making. Therefore, it is quite logical to divide routine ATM decisions into a hierarchy based on priorities and goals from the perspective of each service provider (Table 1). Such a hierarchy provides a higher-level simplified view of decisions made in current operations. It is recognized that the decisions themselves would be different under CE 5 and CE 11, (the decision-maker and DSTs may be different as well) and that other parties as well are making decisions, such as supervisors.

Table 1. Hierarchy of Current ATM Decisions from the ATSP Perspective

Level	Nature	Decision Objective	Decision Maker	Information Needs	Constraints
1	Strategic and NAS wide	Balance system capacity and demand	TFMS	Traffic forecast, weather forecast, system constraints, special needs	Airspace constraints due to weather phenomena
2	Mid-term	Balance capacity and demand and reduce delays	Local Traffic Management Unit (TMU) Specialist	Traffic forecast, weather forecast, local constraints (runway closure, SUA status), and special needs	Airport constraints, ATC workload constraints, airspace constraints (SUA, local weather)
3	Tactical	Ensure conflict free airspace	ATSP	Traffic forecast, potential conflicts	Airport constraints, aircraft constraints, sector constraints

A similar hierarchy can be developed from the perspective of airspace users (e.g., air carriers, general aviation, and military aircraft). In essence, the users create the demand for the airspace. Often, their priorities are to ensure fewer delays and passenger comfort.

Table 2. Hierarchy of Current ATM Decisions from the Airspace User's Perspective

Level	Nature	Decision Objective	Decision Maker	Information Needs	Constraints
1	Strategic (pre-flight)	Ensure optimal route (fuel and time efficiency)	AOC	Traffic forecast, weather forecast, system constraints, special needs	Airspace constraints due to weather phenomena
2	Mid-term (during flight)	Reduce delays and ensure fuel efficiency	FC and AOCS	Traffic forecast, weather forecast, local constraints (runway closure, SUA status), and special needs	Airport constraints, ATC workload constraints, airspace constraints (SUA, local weather)
3	Tactical (during flight)	Ensure hazard free operation (other aircraft, ground, etc.)	ATSP and FC (with Traffic Collision Avoidance System)	Potential with other aircraft and/or ground	Aircraft constraints, airspace constraints

Interestingly, all ATM providers have the same goals: to ensure that aircraft are moved out of their airspace quickly and safely. Since their workload and cognitive demands do not always permit them to explore all alternatives to guarantee optimal (safest and most efficient) routes to all flights, DSTs are important aids to accomplishing these goals. It is argued, moreover, that delegating the responsibility to pilots for their separation may reduce ATSPs' workloads and will allow FCs to select optimal flight plans considering all local constraints (Philips, 2000; NASA AATT, 1999).

6.1 CE 5 Related Decisions

CE 5: Free Maneuvering is aimed at providing optimal trajectories considering the local constraints. Among others, the following are the critical decisions for CE 5 (Philips, 2000; Kopardekar et al., 2001):

- When should the trajectory be changed? When should a solution be considered invalid?
- Why should the trajectory be changed?
- What should be the new trajectory?
- What are the local traffic flow constraints?
- Is there a potential conflict situation?
- How should the conflict be resolved?
- What information needs to be communicated with other parties and how?

- What communication feedback should be expected?
- When should help be sought and from whom?
- When is a situation to be considered dangerous or an emergency?
- What information should be provided under each situation and by whom?
- If adequate information (e.g., weather) is not available, where else can it be obtained?
- When should operations shift from distributed control to centralized control, where ATSP assumes positive control, detects, and solves conflicts?
- When should operations shift from centralized control to distributed control, where the flight deck assumes conflict detection and resolution responsibilities?
- What should be the respective roles of FC, ATSP, AOC, and TFMS under the free maneuvering process?

6.2 CE 11 Related Decisions

CE 11: Terminal Arrival Self-spacing for Merging and In-trail Spacing is aimed at providing reduced spacing to increase capacity and efficiency in the terminal airspace. The following are among the critical decisions for CE 11 (Sorensen, 2000; Kopardekar et al., 2001):

- What should be the optimal spacing between aircraft?
- What conditions must exist for the spacing to be changed?
- What should be the new spacing?
- What are the local airport and airspace constraints?
- Is there a potential conflict situation?
- How should the conflict be resolved?
- What information should be communicated with other parties and how (e.g., what type of intent)?
- What communication feedback should be expected?
- When should help be sought?
- When is a situation to be considered dangerous or an emergency?
- What information should be provided in each situation and by whom?
- If adequate information (e.g., weather) is not available, where else can it be obtained?
- When should operations shift from self-spacing to controller directed spacing?

- What should be the respective roles of FC, ATSP, AOC, and TFMS under self-spacing?

Fundamentally, if we identify answers to above questions, they would serve as the majority of the guidelines.

Though these decisions can be made individually, many pilots making independent decisions and identifying different resolutions about the same issues (e.g., conflict detection) might well create chaos. In other words, this would be an uncoordinated effort among aircraft. Thus certain rules and responsibilities must be in place so that the involved parties know when they are responsible for making certain decisions. Examples include visual flight rules (VFR), or right-of-way rules where preference is given to aircraft on the right side, much like driving.

Better DSTs must be in place to support such operations. Duong and Zeghal, (1997), in an evaluation of Free Route Experimental Encounter Resolution (FREER), indicated that procedures must be in place, particularly for intent information exchange and free flight operations. They recommended that intent information must be broadcast 30 seconds prior to a maneuver. Eurocontrol FREER studies provided rules for free flight operations by extending VFR operations. Extended flight rules (EFR) are a proposed amalgamation of VFR and the autonomous flight rules (AFR) to be implemented in a free flight environment. EFR assigns weighted priorities to aircraft according to their maneuverability, availability in their current flight phase, and the distance to the encounter. The implementation of EFR assumes automatic dependent surveillance-broadcast (ADS-B) and data-link capability.

In order to meet CE 5 and CE 11 goals with due consideration to the constraints identified in Tables 1 and 2, improved information exchange among AOCS, TFMS, ATSP, and FC would be beneficial. Table 3 provides desired information exchanges for CE 5 and CE 11. These exchanges are admittedly incomplete and further information items need to be identified.

Table 3. Information Exchange between AOCS, TFMS, ATSP, and FC

From To	AOCS	TFMS	ATSP	FC
AOCS	Arrival/Departure slots, weather, constraints (to other AOCS)	Aircraft constraints, emergencies	No direct; information exchange	Aircraft characteristics, optimal routes, weather forecast
TFMS	In-trail restrictions, airspace/airport capacity, bottlenecks, weather	N/A	In-trail spacing restrictions, airspace constraints, weather, SUA	No direct information exchange
ATSP	No direct communication	No direct information exchange	Airspace constraints, conflicts, aircraft transfers (to other ATSP)	Local airspace constraints
FC	Experience weather, flight plans, aircraft fuel, required time of arrival, emergencies	No direct information exchange	Conflict resolution plans, experienced weather, aircraft constraints, required time of arrival, emergencies	Routes, slots, conflicts, conflict resolution plan, emergencies (to other FCs)

Clearly, each CE 5 and CE 11 task needs to be carefully examined. Sorensen (2000) and Philips (2000) have provided a detailed description for CE 5 and CE 11 tasks, which could be used as a starting point. Also, the exchanges between tools, between the tool and the operator, and between operators must be identified. Information organized in this manner would benefit system designers.

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7. CONSIDERATIONS FOR THE DAG-TM'S DISTRIBUTED DECISION-MAKING

Based on the literature review, the following aspects of CE 5 and CE 11 specific distributed decision-making need to be considered.

- Klein and Calderwood (1991) pointed out that decision-makers tend to use recognition methods rather than decision tree representations of decision problems. In recognition methods, users tend to fit the decision-making encounter with a prior experienced pattern rather than going through an exhaustive decision tree of multiple alternatives. Such decisions based on strictly prior experience and not exhaustive investigation of alternatives could be suboptimal. DSTs could play an important role in a dynamic environment where optimal decisions are to be made in a limited amount of time. Therefore, DSTs must be developed for optimal decision-making. Other methods, such as training, might prove ineffective, as these would force the controllers to rely on memory.
- Information requirements and exchange among AOCS, TFMS, ATSP, and FC need to be further examined. Increasing operator flexibility in flight management may often be accompanied by the necessity to exchange more information among the system participants (Smith et al., 1997) and when the necessary information is not available, participants may not be able to formulate good decision strategies.
- Roles and responsibilities of AOCS, TFMS, ATSP, and FC need to be clearly identified, particularly for different conditions that cover nominal, off-nominal, management by exception, management by permission, and transitions between them. Procedures that call for intervention by a neutral broker need to be identified as well.
- The roles of decision support tools and the need to harmonize ground- and air-side tools require further examination to ensure that both ATSP and FC get needed and consistent information. Automated tools and capabilities designed to support decision-making should provide the benefits of reduced processing times and optimal decisions (Cardosi & Murphy, 1995).
- However, an excess of reliance on decision aids and automation should be carefully investigated to ensure that the operator is not completely out of the loop and will be able to hand over system management if desired.
- Feasibility and benefits of CE 5 and CE 11 under varying traffic conditions (e.g., low, medium, and heavy), presence of severe weather and rare normal (e.g., emergencies, equipment failures) scenarios need to be investigated.
- The limits of human performance must be carefully understood in order to design displays, decision aids, and procedures that will consider the effect of automation on human performance and ensure that human operators will always be sufficiently involved to take charge of the system if needed.

These considerations provide a framework within which the guidelines were developed.

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8. INITIAL GUIDELINES

As mentioned previously, these are initial guidelines, which are primarily based on literature reviews and discussions with subject matter experts. As more DAG-TM validation studies occur, these guidelines will mature and more specific guidelines will be developed. Based on the available literature related to DDM, CEs, and authors' analysis, the following guidelines are proposed:

Area 1- Roles and Responsibilities

1.1. Knowledge of Responsibility

- a. All parties (e.g., ATSP, FC, and AOCS) must have clear knowledge about who has the ultimate separation responsibility at any instance.
- b. The above guideline could be extrapolated and can be said that it must be very clear to all involved parties what they can and cannot do. For example, FCs may not be able to change flight path without clearance, once they are under positive control of the ATSP.

1.2. Need for a neutral broker

A neutral broker (i.e., ATSP) needs to resolve conflicting and competing goals among airlines, if they arise.

1.3. Locus of control and locus of data should reside at the same location

In a distributed system, the locus of control may be distributed over a number of different individuals or organizations. As an example, within the current NAS, this is the case for preflight planning and the filing of planned routes for aircraft. In this case, FAA traffic managers make some decisions regarding the routes filed, while AOCs make other decisions. If the traffic managers make decisions about severe weather routes without knowledge of the capabilities of the aircraft involved (such as the feasible fuel load or flight crew schedule limitations), they may move flights to routes that are impossible for those aircraft to achieve. Similarly, if AOCs file routes under the National Route Program without knowledge of the traffic flow implications, they may seriously impede departures out of certain airports. Thus, in any distributed system design, one important consideration is whether the locus of control is consistent with access to the relevant knowledge and data needed to make an effective decision.

1.4. Keep ATSP in the loop to maintain situation awareness during free maneuvering

Even during the free maneuvering operation, it is necessary to keep the ATSP involved in order to maintain situation awareness and to sustain the ability to take over the active control of the system. It is recognized that such involvement may be difficult because the ATSP would not be actively controlling traffic. However, communications with the ATSP regarding intent, changes in intent, and conflict management plans should be promoted.

Area 2- DST and Information Needs

2.1. Knowledge of Intent

Both the FC and ATSP need intent information about the aircraft, particularly if they are in a potential or actual conflict. The intentions of free maneuvering and controlled aircraft must be known to the system and should be readily available to other FCs and ATSPs.

2.2. Harmonization of ground and air-side tools

The ground and air-based conflict detection tools need to have similar algorithms, look ahead time, and probe frequency. This will harmonize the conflict detection process. Current conflict detection and resolution systems use different algorithms (e.g., probabilistic vs. deterministic) and parameters for look ahead times. Further research is necessary to ensure that these conflict detection tools detect the same conflicts and resolution algorithms provide similar resolutions.

2.3. Advisory on last point of return to safe separation

If the free maneuvering operation is cancelled either by the FC or ATSP in a conflict situation, the ATSP needs some minimum time to resolve the conflict. Therefore, a DST that prompts an ATSP about such a situation needs to be developed. In most cases, such an alert (i.e., beyond the conflict detection, this is more for conflict resolution much like a last point of return to safe separation) would help the ATSP to cancel free maneuvering and resolve the conflict in a timely manner. Similar advisories are provided to the FC by the TCAS. It must be noted that this item is still a matter of research.

2.4. Need to accurately predict airspace complexity

The ATSPs and TFMs need some way of predicting the complexity of the airspace (e.g., also referred to as Dynamic Density). Currently, a number of Dynamic Density metrics are being validated. This Dynamic Density metric would help ATSPs and TFMs conduct airspace management at a strategic level. It will also help AOCs as they can avoid congested areas and reduce delays.

2.5. Weather information

- a. The same weather information should be available to all system users. Although the same weather information structure (e.g., granularity, grid structure) may not be necessary to all parties, the implication of the weather on operations needs to be standardized. For example, weather at level 3 should have the same meaning for the FC and ATSP. A standard terminology that describes the weather effects needs to be developed. The weather effects should also be categorized based on their impact on flight safety and/or passenger comfort.
- b. Any deviation from the planned intent of an aircraft within a margin of error should be immediately broadcast to the system. In light of September 11, 2001, terrorist attacks, knowledge of such large deviations from planned intent for

unknown reasons (e.g., not for weather or traffic) has become an important element.

Table 4 provides the guidelines, maturity level of each guideline, and appropriate references. The maturity of the guideline is classified as 1, 2, or 3 where 1 indicates that the guideline is premature and needs considerable research to finalize it, 2 indicates that the guideline is somewhat mature but still needs some research, and 3 indicates that the guideline is completely mature.

Table 4. Guideline References

Guideline ID	Guideline	Level of Maturity	Reference
1.1	Knowledge of responsibility	2	16
1.2	Need for a neutral broker	3	43
1.3	Locus of control and locus of data should reside at the same location	2	44, 45, 46, 47
1.4	Keep ATSP in the loop to maintain situation awareness during free maneuvering	2	7, 9, 18
2.1	Knowledge of intent	2	7
2.2	Harmonization of ground and air-side tools	2	7
2.3	Advisory on last point of return to safe separation	1	7, SME input
2.4	Need to accurately predict airspace complexity	2	17
2.5	Weather information	2	45, 36, SME input

There are only few mature (or somewhat mature) guidelines that can be derived from the literature at this time. It is recognized that a number of issues need to be resolved to identify further guidelines. These CE 5 specific issues are:

1. It is not clear from the literature what type of aircraft intent (i.e., state based or flight plan based) should be provided to FC and ATSP. The precise look-ahead time of aircraft intent that needs to be communicated is also not very well understood.
2. It is not clear how separation responsibility should be shared. Is it possible to share the responsibility between the FC and ATSP for separation loss or should the separation responsibility always reside with one party (e.g., explained as a ping-pong model in section A.3)?
3. It is also important to identify the procedures and responsibilities during transitions between free maneuvering to ATSP controlled maneuvering and vice-versa.
4. Although some researchers have investigated flight rules in free maneuvering operations (i.e., VFR or EFR) these flight rules may not be complete and therefore need to be examined further.

5. Phraseology to cancel and resume free maneuvering and to issue traffic alerts needs to be identified.
6. There is an apparent mismatch of expectations and bias between the FC and ATSP while resolving a conflict. Typically, the FC will focus on what is the best available option for their aircraft whereas the ATSP will focus on what is best for the entire airspace and their workload. These “*aircraft-centric*” vs. “*airspace-centric*” perspectives may lead to different resolution strategies (time of resolution and resolution maneuver type). Particularly, such differences would be crucial when the ATSP may feel that the conflict should be resolved more quickly than the FC.
7. It is not clear what and when information should be communicated using data link and what information should be communicated with voice. It is necessary to determine what data should be automatically be entered into the FMS via datalink. Usability of datalink message set, and information presentation needs to be examined.
8. It is also not clear how much feedback should be provided to individual decision makers about their planned or actual decisions. For example, if the ATSP should need to know the impact on flight efficiency each time the flight plan is changed. However, the FC would need to know the implications of potential changes in flight plan on fuel and time efficiency.

It is recognized that there are several studies that are being conducted at NASA Ames, NASA Langley, and FAA William J. Hughes Technical Center that would provide additional input for the next revision of the guidelines.

There are a number of unresolved DDM related issues that need guidelines for CE 11 operations. These issues are:

1. The exact information needs of FCs to maintain their station (winds, ground speed/indicated airspeed, or just ground speed of an aircraft).
2. It is not clear at what point monitoring the spacing buffer actually becomes separation responsibility. In other words, whether separation responsibility starts just before the separation minimum is violated or after it is violated. It is also not clear if such distinction should be made by a FC or by an ATSP.
3. Phraseology to cancel and resume self-spacing and providing traffic alerts needs to be identified.
4. Presentation of how well the spacing between the aircraft is maintained needs to be displayed on the ATSP. Currently, there is no such visual aid. However, the FC's CDTI has a box that identifies if an aircraft is maintaining an appropriate spacing behind the leading aircraft.
5. The current procedure calls for the ATSP to set the spacing in the form of either time or distance. Setting up an optimal spacing based on airport and runway acceptance rate, weather and winds, wake vortex restrictions, and aircraft performance characteristics is not a trivial task and perhaps could not be accomplished optimally by mere experience since a large number of variables contribute to that decision. Therefore, the ATSP must be provided with a DST that considers these factors and identifies an optimal spacing between the aircraft.

9. CONCLUSIONS

DDM is the backbone of the DAG-TM operations. However, guidelines for further research and for system designers need to be developed to promote effective DDM. These initial guidelines are primarily based on the literature review and provide an idea of what is known thus far related to the DDM process related to the DAG-TM. These guidelines will be modified next year, as additional studies provide information.

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APPENDIX A

RELEVANT DISTRIBUTED DECISION-MAKING RELATED LITERATURE

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A.1 Distributed Decision-Making Fundamentals

Decision-making can be defined as a process of choosing a course of action from among two or more alternatives (Roske-Hofstrand & Murphy, 1998). The element of uncertainty often associated with decision-making can be influenced by the decision-maker's individual preferences and experience.

Although there are real world situations where decisions are made in a collaborative fashion, very few decisions are made in a distributed manner, where the decision-making parties are not collocated. With the advent of advanced telephony, the Internet, and video teleconferencing, more business decisions are being made in this collaborative fashion. However, ATM decisions are unique for the following reasons:

- Most decisions are dynamically made often under time pressure,
- Time pressures may preclude conducting an exhaustive search of alternatives (or decision options),
- Safety is always an overriding priority,
- Efficiency and effectiveness of decisions often cannot be predicted,
- Not all parties are collocated, and
- Not all parties have the same information and understanding of the environment.

A.2 Decision-Making Theories

A.2.1 Analytical Decision-Making

The analytical decision theory suggests that a decision maker takes a systematic approach to gathering and analyzing data in order to arrive at a best possible solution to a problem (Allardice, 1998). An analytical approach can help the decision maker to fully develop all necessary information systematically, consider each plausible course of action, and arrive at an optimal solution. When decisions must be made in a short space of time, however, the analytical approach proves less than adequate, because gathering, processing, and analyzing data is a time-consuming process. This approach, moreover, relies on the accuracy and certainty of the data. Typically, the analytical approach does not require a great deal of experience or judgment on the part of the decision maker. Thus the analytical approach to decision-making is a good fit for situations where time is not a constraining factor and a large quantity of accurate and certain data are available.

A.2.2 Naturalistic Decision-Making

Time constraints and environmental dynamics seem to drive decision-makers away from analytical methods towards more intuitive, naturalistic methods. Naturalistic methods suggest that decision-makers work proficiently under time pressure by relying on their expertise to quickly and accurately build mental images of situations (Klein & Zsombok, 1991). Rather than processing large amounts of data to generate and compare several options, experienced

decision-makers use their knowledge and experience to arrive at a comprehension of problem situations (Allardice, 1998). They then select a course of action they deem fit for the situation and run mental simulations to validate or reject the course of action.

A.2.3 Recognition/Metacognition Model

Cohen, Freeman, and Wolf (1996) described a framework for decision-making known as the recognition/metacognition (R/M) model in the context of naval tactical decision-making. Their model describes a set of critical thinking strategies that supplement recognition processes by verifying the results of recognition and correcting problems. Expert decision-makers perceive a large number of situations as familiar and generate an appropriate response. However, should recognition fail under uncertain or novel situations, skilled decision-makers supplement recognition with processes that verify results and correct problems in novel situations that fit no familiar pattern. They reflect on and improve the results of recognition, but do not reject it. In other words, skilled decision-makers are also metacognitively proficient, that is, they have a situation picture and plan balanced by an appreciation of its potential weaknesses (Figure 1).

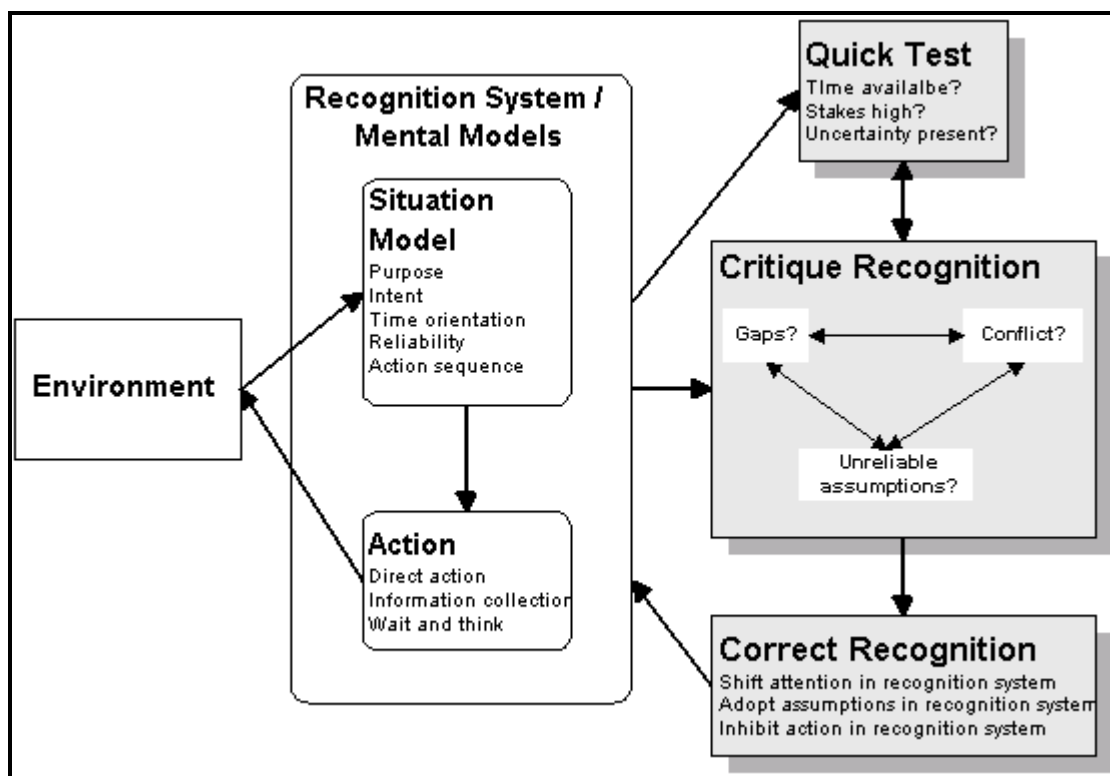


Figure 1. Recognition/Metacognition Model of Decision-Making
(Cohen et al., 1996)

In familiar situations, they make decisions by the recognitional process shown in Figure 1. “Quick test” is a control function that decides whether to act on the response immediately or to think about it longer. If the situation is unfamiliar and time permits, then a cycle of critical thinking about the decision-maker's mental model is triggered. Critiquing and correcting one problem may lead to the creation of and detection of other problems, triggering new cycles of correction and evaluation. This cyclical process ends when the cost of delay becomes too high or the uncertainty is resolved. Critical thinking involves looking for qualitatively different kinds of uncertainty in a mental model and dealing with each uncertainty in appropriate ways. In critiquing and correcting, the decision-maker may find gaps (not enough reason for choosing one solution over the other), conflict (reasons to chose both conclusions) or unreliable assumptions (reasons that depend on unexamined grounds).

Bergstrand (1998) describes two primary methods of decision-making. Analytical Decision-making (ADM) refers to the use of algorithmic methods to determine a course of action. The ADM process tends to ignore intuitive guidance and requires accurate and detailed information to make decisions. One method utilized by the Canadian military to quantify optimal solutions is the Multi-Attribute Utility Analysis. Naturalistic Decision-making (NDM) refers to methods that rely on intuitive guidance to make decisions. NDM works best in situations where: there is limited time available, decision-makers have a high level of knowledge of the system, there is a high degree of uncertainty, the level of risk is great, there are multiple possibilities of vectoring, and there is a need for resourceful solutions. Bergstrand (1988) stresses the need to combine both ADM and NDM processes in order to match the method to the needs of the situation. Both methods have advantages and disadvantages.

Loy (1998) asserts that NDM is a redundant concept that makes no significant contribution to cognition research. Evidence suggests that real world decisions are made in a variety of ways and classical decision-making involves the use of calculative cognitive processes. NDM should be restricted to areas that require decisions be made within a time critical framework and within high-risk contexts.

A.2.4 Decision-Making Classification Based on Time Horizon

There are few domains outside ATM (other than nuclear power plants) where decision-makers experience such stringent constraints and time pressure. Usually, the decision-making process can be categorized in four ways (Hollnagel, 1998):

- Scrambled decisions are made under high time pressure and in an almost haphazard manner, where the decision maker does not have enough resources and time to investigate range of decision alternatives. A majority of scrambled decisions are reactive rather than proactive.
- Opportunistic decisions are also made under time pressure, but the decision maker has a little more time to investigate decision alternatives. In other words, the decision maker looks for opportunities to make more efficient and effective decisions if and when possible.
- Tactical decisions are made with a slightly longer outlook. The decision-maker has more time to make effective and efficient decisions.

- *Strategic decisions* are made with a long-term perspective. The decision-maker has adequate or more than adequate time to make effective and efficient decisions, most of which are proactive rather than reactive.

The key distinguishing factors between these four types of decisions is the amount of control the decision-makers can command in the situation. From scrambled to strategic decisions, the decision-maker's mode of operation can be described as evolving from reactive to proactive. However, these decision-making classifications are based on the state of an operator largely applies to one or a relatively few operators who work very closely together.

A.2.5 Decision-Making Necessities

Most decision-making theories indicate that humans are not the best decision-makers using analytical decision-making processes even though analytical decision-making processes would lead to optimal decisions (Klein & Calderwood, 1991). This is largely due to complexity of decisions, the number of alternatives that need to be investigated, and uncertainty of information. However, if decision-makers are provided with decision support tools (DSTs), they could make optimal or near-optimal decisions with the analytic approach rather than the recognition model.

For CE5, it would clearly mean that any DST that investigates and suggests conflict-free trajectories that are most fuel and/or time efficient would be beneficial rather than depending on a human operator to investigate the range of trajectories and conduct mental calculations. Interestingly, NASA's Direct-to DST provides such a decision aid.

For CE-11, higher capacity in the terminal area would be achieved with the promotion of self-spacing for merging and in-trail spacing. The premise is that self-spacing FCs will be able to reduce spacing between successive aircraft because they would be primarily concerned with their own separation whereas controllers would be responsible for the entire airspace and are likely to maintain larger separation buffers between merging and/or in-trail aircraft. The controllers have to make complex decisions that satisfy constraints for the entire airspace whereas FCs have to make decisions for their own aircraft. The controller's decision-making complexity may be much greater than the FC's since they are particularly involved in the investigation of a range of merging, in-trail possibilities, and identifying an optimal option. Therefore, a decision aid that investigates a range of possible solutions to aircraft sequencing to provide tighter spacing would be beneficial.

The four agents -- TFMS, AOCS, FC, and ATCS -- make ATM-related decisions depending on the circumstances and operating environment. Currently, ATCS makes separation-related decisions except when the Traffic Alert and Collision Avoidance System (TCAS) provides alerts and resolution advisory to pilots. DAG-TM concepts largely shift the separation responsibility to the flight deck. Shifting responsibility allows reduction of controller workload and provides more autonomy to the FC and their operations. Since shifting the responsibility to the flight deck creates the same complex decision-making situations, the FC would also benefit from effective decision aids that use analytical decision-making processes.

A.2.6 Decision-Making Styles

Certain decision-making styles can apply to CEs 5 and 11, as follows:

- *Division of responsibilities*: It is well recognized that a large number of decisions are made in ATM every day. Since it is impossible for one person to make such a large number of complex decisions, the current ATM system distributes decision-making among a number of individuals and parties (e.g., strategic decisions by TFMS, tactical decisions at sector level by ATCS, etc.) (Smith, McCoy, & Orasanu, 1998).
- *Collaborative decision-making*: This style of decision-making involves most or all parties (or stakeholders) in the decision-making process. It is important particularly if the stakeholders have different (often competing) interests and there is no single overriding factor.
- *Shared decision-making*: This style is very similar to collaborative decision-making with the possible exception that sharing parties might be a subset of all stakeholders.
- *Delegated decision-making (ping pong concept)*: Here authority is delegated to one party. Such delegation could be dynamic and decision-making authority could shift from one party to another much like a ping-pong game where the ball is hit back and forth between two players.
- *Democratic decision-making*: Stakeholders are allowed to provide individual input after which their choices are counted (or ranked by preference) to select one among many alternatives.
- *Autocratic decision-making*: One party makes a decision for all stakeholders. Such decision-making can be very efficient, but its effectiveness largely depends on the integrity of the decision-maker.

A.3 Prior Research Related to Concepts Similar to DAG-TM

The free flight concept suggests placing more responsibility on FCs to maintain safe separation from other aircraft in the National Airspace System (NAS). This idea could shift decision-making responsibility from air traffic controllers to FCs (RTCA, 1995; FAA, 1998). Therefore, without a clear understanding of the distributed decision-making process, free flight would not be a reality. Various levels of distributed decision-making concepts include collaborative decision-making; the “ping-pong concept,” where decision-making is delegated to two or more parties; and self-separation, where ultimate responsibilities lie with one party.

Koenig (1995) discussed the fundamental issues involved with adapting crew resource management (CRM) from the flight deck to ATC management. The team environment is very different between FCs and ATSPs. A FC usually works as a team with a clear hierarchy of command structure while ATSPs usually work as a team with a hierarchy that is more horizontal in nature. Multiple controllers all work with the same level of authority under one supervisor. Four main CRM issues were identified by the Air Traffic Teamwork Enhancement steering committee in 1992, with respect to ATC:

- The work environment rewards individual efforts, not team efforts,
- Controllers learn to survive rather than grow,
- Some controllers are reluctant to ask for help, and
- Communication tends to be poor at many levels.

There is clearly a need to promote trust among controller team members and between controllers and pilots.

Several studies have investigated various aspects of the implementation of free flight and distributed decision-making. A recent study (Air Ground Integration Experiment [AGIE]) investigated the shared-separation concept that utilized distributed decision-making revealed some interesting results (FAA & NASA, 2001). Results indicated that controllers preferred conventional scenarios where decision-making authority lay with them, whereas pilots preferred free flight scenarios where *they* held decision-making authority. Controllers and pilots also had different styles in solving conflicts. Controllers tend to solve conflicts earlier than pilots, using more altitudes and headings, while pilots solve conflicts later, using more headings and speed changes. Controllers also cancelled free flight operations in some cases whereas pilots did not. The controller's DST (User Evaluation Request Tool [URET]) had a conflict look-ahead time of 13-20 minutes; whereas, pilot's decision support tool (Cockpit Display of Traffic Information with Alert Logic [CDTI-AL]) had a conflict look ahead of approximately 7 minutes. The study reinforces that such critical DST parameters need to be harmonized. The controllers felt uncomfortable when pilots resolved conflicts much later than controllers would have. One participant controller suggested considering different separation minima for pilots (i.e., 10 nm) and controllers (5 nm) to allow controllers to take over from pilots a bit earlier.

Endsley, Sollenberger, Nakata, and Stein (2000) reported enhanced displays might provide help for controllers under free flight conditions. Kerns (1999) conducted a study on the usefulness of conflict detection tools (i.e., URET) in helping controllers manage traffic in an unstructured environment. Controllers indicated that safety was enhanced with URET, which benefited their management in free flight conditions. Pekela and Hilburn (1998) explored ATC and pilot tools and procedures required for free flight. They identified a need for vertical and horizontal dimensional display for ATC, and better conflict detection and resolution tools.

Studies investigating the effects of shared separation or distributed decision-making on human performance have found that controller situation awareness (SA) decreases, and both workload and communications requirements increase, when they need intent information (Endsley, Mogford, Allendoerfer, Snyder & Stein, 1997; Endsley 1997). However, the AGIE results indicated that the controllers' SA was high even in scenarios where pilots were responsible for separation decision-making, possibly because the pilots might have cancelled free flight and requested to delegate decision-making to controllers. The controllers also tended to cancel free flight when they did not have intent information. Hilburn, Bakker, and Pekela (1998) also noted the importance of aircraft intent information for controllers during free flight situations, observing more reported conflicts from controllers who had no intent information, and implying that sharing intent information would increase perceived safety. Interestingly, they also found, contrary to AGIE findings, that in a shared separation environment, controller workload was reduced by the use of free flight, and noted controllers' mistrust of automated conflict detection tools.

Fleming, Lane, and Corker (2000) examined various levels of decision-making, separation authority, and mixed equipage. They found that controllers were likelier to take direct control of aircraft in shared-separation scenarios when more aircraft self-maintained separation. They emphasized the controllers' need for tactical aircraft intent information. Cashion and Lozito (1999) examined the impact on FCs of different levels of intent in the airborne alerting logic. They found that crews prefer longer-term intent (i.e., intent that includes lateral and vertical navigation components of the flight management system), though they did express concern about display clutter with more intent data on the CDTI.

Mackintosh et al. (1998) provided FCs with prototypic airborne alerting logic and CDTI display tools to help them with separation tasks, and found longer conflict detection times in higher-density compared to low-density traffic scenarios. Johnson, Battiste, and Holland (1999) have provided guidelines related to CDTI features that might be required in a free flight operational environment. Their research suggests that color-coding and 3-D flight plans for alerting and SA might be critical to the successful implementation of shared-separation. Smith, Billings, McCoy, and Orasanu (1999) found potential advantages in making available to pilots added tools like enhanced weather displays and conflict alert probes. They indicated that the decision-making process becomes increasingly complex as more decision-makers are placed in the loop and communications increase. They also commented that controllers might lose some efficiency and SA if their management role were changed to monitoring. They concluded that cooperative flight planning and information sharing during routine bottlenecks or constraints would improve operations.

Smith et al. (1998) indicated that controllers would be adding a new role as information providers in the future systems. They stated that in some instances controllers will merely provide information (i.e., advisories) but in others will play more active roles. They also identified:

- The intentions of aircraft in free flight,
- The intentions of aircraft not performing in free flight,
- The weather information,
- The possible planned events including potential deviation of aircraft from their intentions, and
- The availability of reasonable implications for the rules.

Using a brainstorming session the authors concluded from the participant responses that:

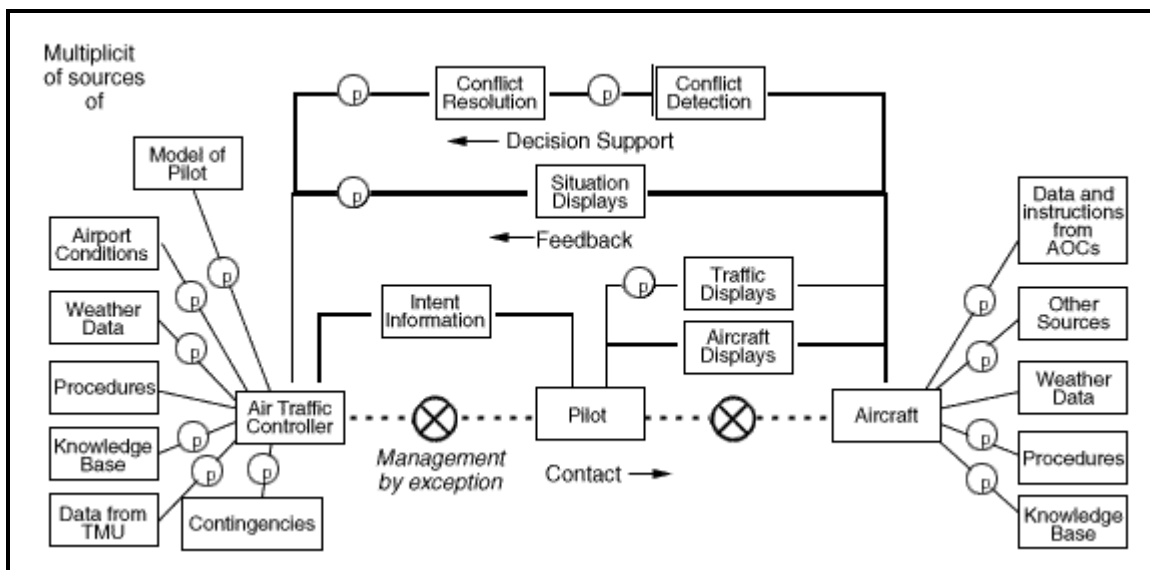
- ATSPs and FCs need to know the planned routes in any given sector,
- FCs must instantly convey any changes to the flight plan to ATC, and
- FCs that choose to change a flight route and to hand fly aircraft must coordinate their intentions verbally to all FCs and dispatchers.

Duley and Parasuraman (1999) concluded that controller information needs must be carefully considered before determining the role and structure of a DST. They indicated that information management systems should be sufficiently adaptive so that information presented is based on situations, and specifically that the ATM system must allow controllers to decide when to take positive control or to delegate authority to an automated system. Such an adaptive, context sensitive system would alter the nature and presentation of information based on situations.

Corker, Gore, Fleming, and Lane (2000) developed a predictive human performance model that addresses the impact of distributed self-separation operations on ATSPs. For the experiment, four modes of control were provided: current operation with positive ground control; current operations with direct routing; twenty percent of the aircraft in the sector free maneuvering and self-separating; and eighty percent free maneuvering and self-separating. Results showed that the controller operating in extensive maneuvering conditions found the task of monitoring traffic workload intensive (independent of the communications tasks associated with positive ATC), thus indicating that some form of information aid is required. Participants were especially keen to receive intent information.

A.3.1 Role and Importance of Decision-Making in DAG-TM

ATM is a highly dynamic system and its descriptive data constantly changes, sometimes in an unanticipated way. Weather gives us a perfect example. The following model by Smith, Billings, et al. (1997) depicts the sources of variance in ATM data (see Figure 2).



“p” represents a source of variability in the process

Figure 2. Sources of Variance in ATM Data (Smith et al, 1997)

A.3.2 Issues with Distributed Decision-Making

DAG-TM aims to give ATM users more flexibility in making decisions based on their business concerns yet subject to constraints that assure safety and efficient use of system capacity (Jacobsen, 2000). Since factors such as inclement weather and traffic congestion prevent a route or route segment from accommodating a particular flight, such restrictions need to be communicated to the dispatchers so that they can reconsider their pre-flight planning (Smith, Billings et al., 1997). This implies that dispatchers making decisions require knowing the intentions of the ATM system. The authors identified the following questions, arising from the need of sharing intent information pertaining to strategic and tactical decision-making:

- Can tools be developed to help identify inappropriate routes based on weather and traffic information?
- Can tools be developed to help disseminate such restrictions to airline operations centers so that they can plan more efficiently and effectively?
- How can intent information be made available in an efficient and effective fashion?
- How can coordination be achieved to ensure timely and effective use of intent information?
- How will controllers who are monitoring a situation determine when they need to intervene?

The success of team decision-making relies heavily on the satisfactory manipulation of available information (Hammond, Harvey, & Koubek, 2000). As decision-making environments become more complex and data-intensive, the use of automated decision aids is likely to become more common and more critical to the process (Moiser & Skitka, 1996). Automated decision aids act as decisional cues to help decision-makers choose a course of action with minimal cognitive effort. However, focusing on these cues may draw attention from less obvious but equally important information.

Ball, Hoffman, Chen, and Vossen (1996) identified main objectives for collaborative decision-making (CDM) as follows:

- Generation of better information by merging flight data with airspace system knowledge,
- Creation of shared SA by distributing the same information to users and providers, and
- Creation of tools and procedures to allow users to respond directly to capacity/demand imbalances and to collaborate with TFMS to agree upon coping strategies.

They proposed pairing two interesting approaches to CDM: ration-by-schedule (RBS) and inter-airline arrival slot swapping. The RBS rations the available arrival capacity to different airlines and then the airlines swap slots among flights to meet their economic objectives. The authors pointed out a maxim of the CDM: "More information is better," but suggested that individuals could get overloaded with information. Airspace managers are very susceptible to

information overload since they make real-time decisions under time pressures with severe safety consequences. Thus they raised these CDM human factors issues:

- Which parties need information and in which form?
- Should all parties have the same information?
- At what point does operational information become proprietary?
- At what point does information availability become counterproductive?
- How do we measure the value of information exchange and how do we weigh it against the cost of start up and maintenance?

Lindsey's (1998) study to determine issues involved with aviation weather reporting suggests requirements for the optimal integration of weather systems. A concept of CDM was developed to share weather information. Substantial costs can be saved by sharing weather data, such as turbulence reports. Some airlines sell their turbulence forecasts to other carriers. It is important that standardized reporting mechanisms be adopted to accurately share information to reduce confusion. Pilots may find that weather data becomes more essential during free flight operations and with tactical decision-making within terminal areas.

Hammer (1965) also studied the effects of the amount of information provided and the feedback of results on decision-making efficiency. He observed that in military scenarios, increasing task difficulty by limiting information induces a lack of confidence in making accurate decisions and hence may cause a delay in making a final decision. Therefore, the amount of information must be carefully presented to the decision maker.

A controller's perception, attention, and memory play vital roles in ATC problem-solving and decision-making (Cardosi & Murphy, 1995). Hence it is important that system design exploit human capabilities and compensate for human weaknesses. Parasuraman, Molloy, Mouloua, and Hillburn (1996) indicated that human factors professionals need to come up with a better approach than "watch the computer" (i.e., monitoring only) in the face of increased reliance on automation in ATM (and other highly complex systems). The effects of automation and other decision aiding systems need further study, according to a report from Lockheed Martin (1998). Research indicates that SA levels may be lower in passive viewing conditions than in active decision-making. ATC systems should be designed to compensate for controllers weaknesses. Controllers need clear displays that are reliable and predictable, visual feedback for changes in state, more visibility of less common events, redundant communications, and visual backups wherever memory errors can be significant. The report notes the need to increase consistency between information displayed on the flight deck and corresponding ATC systems.

ATM, like all systems based on distributed control, need a more collaborative approach to decision-making, based on effective information sharing among system operators (Smith et al., 1997). The authors' model of shared ATM system control and coordination is shown in Figure 3.

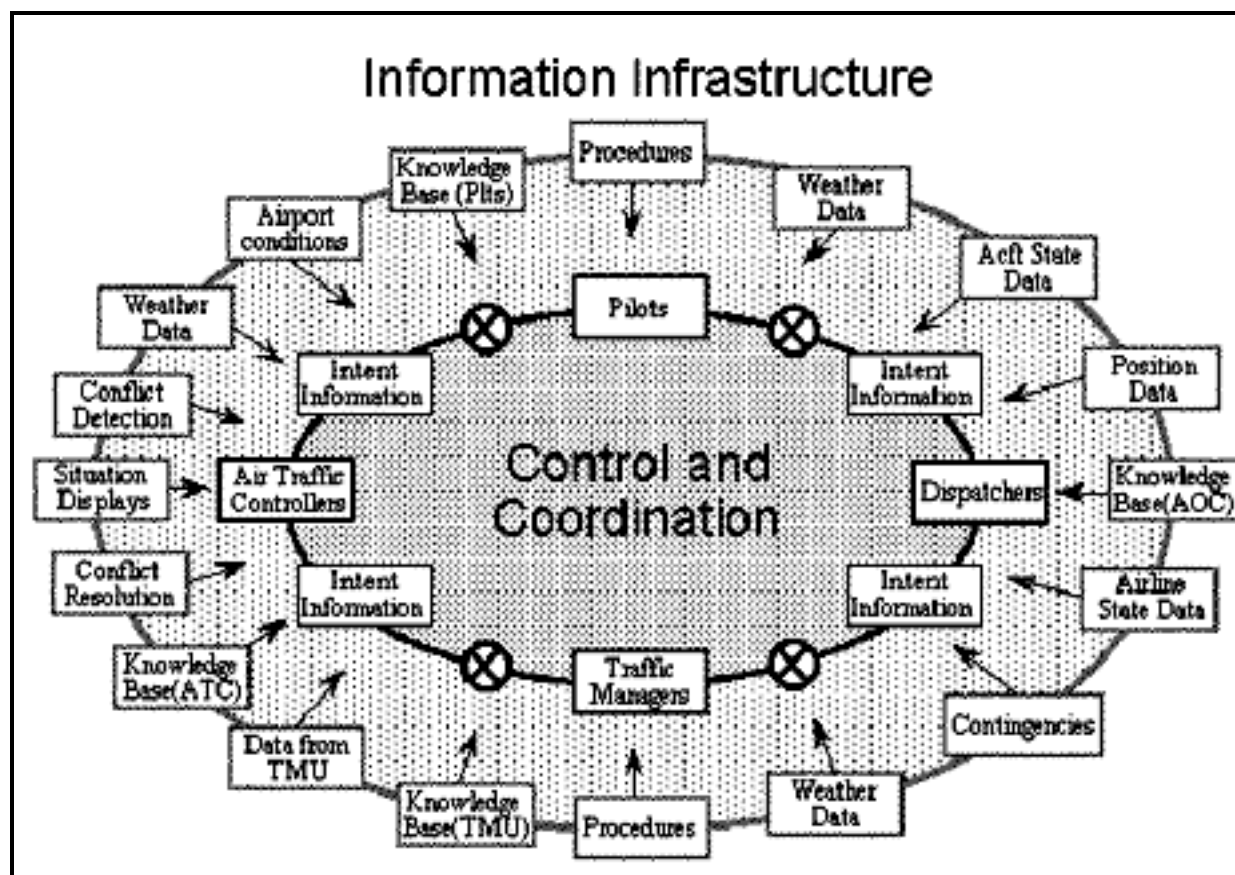


Figure 3. Shared ATM System Control and Coordination (Smith et al., 1997)

The model in Figure 3 shows decision-making as widely shared between controllers, pilots, traffic managers and dispatchers, and supported by an infrastructure that makes information readily accessible to the system operators as and when they need it to formulate good decision strategies. The model suggests that the pilots, dispatchers, traffic managers, and ATSPs need a better understanding of how system and decision components interact. It is important that dispatchers and traffic managers know how their strategic decisions impact the tactical decisions of FCs and ATSPs, and vice versa.

In another study, Smith, McCoy, and Orasanu (1998) held a focus group session to explore issues related to interactions between AOC and Air Traffic Control Systems Command Center (ATCSCC). They indicated that the dispatcher has the responsibility for preflight operations (along with a pilot in command) and the release of an aircraft. Overall, the dispatcher was concerned with cost, safety, timeliness, and passenger comfort. The AOCS is responsible for monitoring flight progress, issuing safety information for the flight, and canceling or redispatching any flight that cannot operate safely as planned, or continue to operate safely as released. The ATSPs, who are responsible for strategic planning in the ATM, interact with the AOCS and local Traffic Management Units (TMUs) to plan daily traffic flows and restrictions. The focus group discussions indicated the importance of creating a shared understanding by sharing goals and constraints, to distribute responsibilities where each individual has a primary goal and responsibilities, and to manage process feedback, i.e., to explain rather than simply dictate route rejections. An interesting observation is that dispatchers are really scheduling people (FCs, flight attendants), not merely flights. Complications regarding work schedules are

often difficult to convey to ATSPs, whose primary focus is on the safety and efficiency of aircraft. One solution the authors suggested is a computerized online communication network of choke points, or points of congestion. Such a real-time database would help AOCS plan to avoid choke points, and thus lift a burden from ATSPs.

Questions raised by Smith, Woods, et al. (1998) regarding typical ATM operations include:

- What types of additional specifications are needed to fully specify a free flight environment?
- What factors need to be considered in shifting the locus of control from a FC to a controller?
- What roles should controllers play in a free flight system?
- What communication protocols and technologies are needed to support these new roles?
- What knowledge is needed about intentions in order to operate successfully within an en route free flight environment?

The authors also identified the following information needs for ensuring shared SA in order to amend a flight plan:

- The intentions of aircraft participating in the free flight,
- The intentions of aircraft not participating in the free flight,
- The weather,
- Identification of possible unplanned events, including potential deviations of aircraft from their intentions, and
- Identification of availability of reasonable contingencies for dealing with unplanned event.

Based on the above needs, they recommended the following technologies:

- Tools to support cooperative work involving traffic managers, controllers, FCs, and AOCs,
- Communication links (air-to-ground, air-to-air, ground-to-ground),
- Conflict detection and resolution,
- Cockpit and ground-based situation displays, and
- Tools for strategic and tactical planning.

Harper, Mulgund, Guarino, Mehta, and Zacharias (1999) indicated that distributed decision-making suggests an adversarial approach, particularly when one aircraft has to move into a conflict situation. They propose a principled negotiation approach that searches for solutions providing the greatest mutual gain for the players' individual goals. In this way a balance arises between the search for satisfying solutions and the adversarial bargaining process between individual pilots to achieve local goals. Several researchers investigated the shared-separation responsibility issue from the flight deck's perspective. A key issue is that a FC might simply hand over the responsibility to the controller if they cannot solve a problem in a timely manner (FAA & NASA, 2001). Ballin, Wing, Hughes, and Conway (1999) noted that the controller is not required to accept such a responsibility. Since this issue is critical for safety, it needs a thorough investigation and may have considerable procedural implications.

In some situations, decision-making requires human reasoning about uncertainty and consideration of data not easily communicated to a computer. In such cases, humans will maintain responsibility for integrating relevant information to make decisions (Smith, Billings, et al., 1997). Smith, Woods, et al. (1999) working with a total of 40 controllers, dispatchers, pilots, and traffic managers noted that the future ATM would benefit from the following:

- Changing roles and information requirements,
- ATCS access to airline business needs,
- Delegation of separation responsibilities to FCs,
- Coordination during transitions in level or locus of control to offer flexibility, and
- Paradigms of distributed control where control by direction, permission, or exception would be explored.

They raised a number of human factors issues associated with the future ATM. These include:

- How to ensure adequate involvement of various parties so that they maintain SA and know who is in control?
- What are the technology needs and how can they be made to support individual performances as well as cooperative performance?
- How can the workload be predicted and managed?
- What situations may cause goal conflicts and when would a referee be needed?

Smith et al. (2000) proposed three alternative rules of the game for the NAS operation. They suggested that the current operational practice uses "management by direction," where ATSPs assume positive control. Such operations can shift to "management by permission," wherein users operate on preferred routes, request exceptions to such routes and providers review constraints while granting their requests. Under this paradigm, there will be a greater need for TMU and AOC to exchange information, primarily on the users' understanding of the provider and system constraints, and the providers' understanding of users' economic and operational costs. A major limitation here is increased communications and interactions between TMUs. So a third alternative was suggested. "Management by exception" opts for a

transfer of control between TMUs to AOCs in which AOCs are permitted to file desired flight plans. The ATM provider automatically accepts these flight plans unless environmental conditions require more central control. Clearances are issued only if weather or traffic contingencies permit. This paradigm is observed under the FAA's enhanced National Route Program. The authors pointed out two main weaknesses of this approach: inefficient use of some airspace due to inadequate distribution of relevant information and knowledge, and a lack of an independent decision-maker (e.g., referee) to allocate limited resources. The lack of a neutral resource broker may significantly reduce overall system capacity. Recognizing the problems of such paradigms, the authors promoted the CDM program where a wider information exchange promulgates provider and user priorities. CDM examples are as follows:

- *Increasing knowledge dissemination:* Here it is recognized that online exchange between AOCs and TMUs although valuable is limited due to time constraints. A post-processing tool is used to identify routine bottlenecks before flight.
- *Management by control with increased flexibility:* Under resource constraints (e.g., airspace constraints and imposed in-trail restrictions), providers can offer alternatives and let users select alternatives that suit their needs best.
- *Changing parameter of control:* Instead of controlling the number of arrivals in the airspace, TMUs restrict the number of slots an airline is allocated. The airlines then prioritize flights and weigh their business objectives (international flights may be more important than regional flights).
- *Use of a neutral broker:* Arrival slots not expected to be met are swapped by a neutral broker to increase efficiency. The airline that gives up the slot can now use one vacated by another aircraft that took its slot.
- *Shifting locus of control to match the locus of data:* Information related to constraints is communicated to AOCs, who are encouraged to resolve problems among themselves. In competitive situations, a neutral broker intervenes. FAA's Low Altitude Arrival and Departure (LAADR) program involves cooperation between FAA traffic managers and AOCs. In order to reduce ground delays around New York, lower level altitudes are used for arrivals and departures. The TMUs decide which flights to assign to LAADRs with AOC cooperation. Instead of setting up blanket departure stops, some departure altitudes are adjusted to reduce congestion in high altitude sectors and relieve gates. AOCs provide preferences for certain flights (e.g., short range rather than international flights).

Though they recognized that committee decision-making would be a less efficient method under time pressures, the authors suggested that consultation and collaboration prior to decision-making could considerably improve NAS performance.

Andersson and Hall (2000) conducted a study to evaluate the benefits of collaborative arrival planning on air carrier ground operations. Information was distributed through the Traffic Management Advisor and the Final Approach Spacing Tool. Results indicate significant benefits from increased communications and collaboration during the arrival process. The estimated decrease in the standard deviation of the landing time estimate error from 5 to 3 minutes could have avoided 500 passenger-minutes of delay (pmd) during a 3.25 hr period operating on schedule, or 2000 pmf during a 3.25 hr period experiencing significant delays. Allowing an airline to shift an aircraft's landing time by as little as 6 minutes could save 5500

pmd. Furthermore, 6 minutes of sequencing flexibility could save 1 million pmh over one month, or 12 million pmh over one year.

In summary, the literature review indicated the need to further conduct research related to distributed decision-making:

- Appropriateness and applications of different distributed decision-making styles,
- Impact of distributed decision-making on human performance,
- Information and DST needs,
- Impact of aircraft mix on distributed decision-making operations,
- Roles and responsibilities of ATC, FC, AOCS, and TFMS,
- Ability to switch/transition decision-making among multiple parties, and
- Procedural needs and implications.

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ACRONYM LIST

AATT	Advanced Air Transportation Technologies
ADM	Analytical Decision Making
AFR	Autonomous Flight Rules
AOC	Airline Operations Center
AOCS	Airline Operations Center Specialists
ATC	Air Traffic Control
ATCS	Air Traffic Controller Specialist
ATCSCC	Air Traffic Control Systems Command Center
ATM	Air Traffic Management
ATMSDI	Air Traffic Management System Development and Integration
ATSP	Air Traffic Service Provider
CDM	Collaborative Decision-making
CDTI-AL	Cockpit Display of Traffic Information with Alert Logic
CE	Concept Elements
CRM	Crew Resource Management
DAG-TM	Distributed Air-Ground Traffic Management
DST	Decision Support Tool
EFR	Extended Flight Rules
FAA	Federal Aviation Administration
FC	Flight Crew
FREER	Free Route Extended Encounter Resolution
LAADR	Low Altitude Arrival and Departure
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NDM	Naturalistic Decision-making
nm	Nautical Mile
pmd	Passenger-Minute Delay
RBS	Ration-by-Schedule
R/M	Recognition / Metacognition
SA	Situation Awareness
TFMS	Traffic Flow Management Specialist
TMU	Traffic Management Units
VFR	Visual Flight Rules

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